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A vision for hydrogen economy in Pakistan

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ABSTRACT

Fossil fuels possess very useful properties not shared by non-conventional energy sources that have made them popular during the last century but unfortunately they are not renewable. Since the oil crisis of 1973, considerable progress has been made in the search for alternative energy sources. Among the candidates, hydrogen holds a pre-eminent position because of its high energy content, environmental compatibility and ease of storage and distribution. Hydrogen can be produced in a variety of ways. Water electrolysis is one of the most utilized industrial processes for hydrogen production. This article discusses advantages and disadvantages of hydrogen energy. Besides, barriers and challenges to hydrogen economy have been summarized. The current energy situation in Pakistan is presented followed by a road map to hydrogen economy in Pakistan. It is concluded that a combination of fuel cells and a hydrogen infrastructure is a way forward to combat the long-term challenges of climate change and energy security for Pakistan. The hydrogen economy potentially offers the possibility to deliver a range of benefits for the country; however, significant challenges exist and these are unlikely to be overcome without serious efforts.

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1. Introduction

Hydrogen comes from the Greek words “hydro” and “genes” meaning “water” and “generator”. Hydrogen, the first element in the periodic table, is the least complex and most plentiful element

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in the universe. Hydrogen is a key component of water, which covers over 60% of the planet's surface. Hydrogen appears in different forms in plants, animals, humans, fossil fuels, and other chemical compounds.

1.1. Hydrogen as an energy carrier

Fossil fuels possess very useful properties not shared by non-conventional energy sources that have made them popular during the last century. Unfortunately, fossil fuels are not renewable. In addition, the pollutants emitted by fossil energy systems (e.g., CO, CO_2, C_nH_m, SO_x, NO_x, radioactivity, heavy metals, ashes, etc.) are greater and more damaging than those that might be produced by a renewable energy system. Since the oil crisis of 1973, considerable progress has been made in the search for alternative energy sources. Among the candidates, hydrogen holds a pre-eminent position because of its high energy content, environmental compatibility and ease of storage and distribution. Hydrogen is not exactly an energy source, but a chemical energy carrier. The use of hydrogen is a long-term option to reduce CO_2 emissions. Hydrogen is expected to replace liquid and gaseous fossil fuels as the preferred fuel for transportation by the end of this century [1,2].

1.2. Hydrogen production

Hydrogen is perceived as a clean fuel. The key question is from which source hydrogen can be produced in a sustainable manner in large quantities and at acceptable cost. An important aspect is to avoid that hydrogen becomes just a more expensive way of harnessing fossil fuels [3].

Currently 500 billion m^3 of hydrogen, equating to about 6.5 EJ of energy, are produced annually worldwide. Approximately, 99% is produced from fossil fuels, mainly by steam reforming of natural gas which is mostly made up of methane. It is possible to produce hydrogen using other production techniques and different energy sources. Water electrolysis is one of the most utilized industrial processes for hydrogen production. About 108.7 kg of hydrogen can be produced from 1 m^3 of water by electrolysis, and the energy of this amount of hydrogen is equivalent to that of 422 l of gasoline. The electricity for electrolysis can come from fossil or renewable energy sources. Photosynthetic bacteria represent a method with appreciable extent efficiency for hydrogen evolution using solar energy [1,2].

Certain hydrogen production processes have reached maturity for commercial exploitation: (a) steam reforming of natural gas; (b) catalytic decomposition of natural gas; (c) partial oxidation of heavy oils; (d) gasification of coal and other heavy hydrocarbons and (e) steam–iron coal gasification [1,2].

It has been shown that although renewable energy resources cannot entirely satisfy the energy demand but electrolysis associated with solar energy, wind power, hydropower and biomass can lead to significant hydrogen production [4].

In an experiment, hydrogen and methane were produced from wastewater sludge. The results suggest that production of hydrogen and methane from wastewater sludge through a series of two reactors is feasible [5].

Hydrogen generation from water using nuclear energy has been examined in Japan. It is found that the high temperature gas cooled reactor (HTGR) has a possibility to generate hydrogen economically compared with other types of nuclear reactors. As for long-lived radioactive waste to be generated by nuclear reactors, it is expected to significantly reduce its burden to the human environment by applying transmutation technologies [6].

1.3. Advantages and disadvantages of hydrogen energy

Some important advantages of hydrogen are listed below [1]:

- Hydrogen is a non-toxic, clean energy carrier that has a high specific energy on a mass basis (e.g. the energy content of 9.5 kg of hydrogen is equivalent to that of 25 kg of gasoline).
- Hydrogen can be safely transported in pipelines.
- Hydrogen can be used as an energy carrier in clean sustainable energy systems.
- When combusted, hydrogen produces non-toxic exhaust emissions, except at some equivalence ratios (where its high flame temperature can result in significant NO_x levels in the exhaust products).
- Compared to electricity, hydrogen can be stored over relatively long periods of time.
- Hydrogen can be utilized in all parts of the economy (e.g. as an automobile fuel and to generate electricity via fuel cells).

Some disadvantages of hydrogen follow [1]:

- When mixed with air, hydrogen can burn in lower concentrations and this can cause safety concerns.
- Storage of hydrogen in liquid form is difficult, as very low temperatures are required to liquefy hydrogen.

1.4. Hydrogen economy

The transition to a hydrogen-based energy economy, where the main chemical energy carrier is hydrogen and the main non-chemical energy form is electricity, is being made gradually, and is likely to continue to the middle or end of this century. The optimal endpoint for conversion to the hydrogen economy is the substitution of clean hydrogen for the present fossil fuels. The production of hydrogen from non-fossil fuel sources, such as solar, hydropower, wind, nuclear, etc. becomes central for better transition to hydrogen economy [1,2]. A hydrogen-based sustainable energy system is described pictorially in Fig. 1.

Salient features of a hydrogen economy will be as follows [7]:

- A hydrogen-based energy system will increase the opportunity to use renewable energy in the transport sector. This will increase the diversity of energy sources and reduce overall greenhouse gas emissions.
- Hydrogen in the transport sector can reduce local pollution, which is a high priority in many large cities.
- The robustness and flexibility of the energy system will be increased by the introduction of hydrogen as a strong new energy carrier that can interconnect different parts of the energy system.
- The targets for reducing vehicle noise may be met by replacing conventional engines with hydrogen-powered fuel cells.
- Fuel cells for battery replacement and backup power systems are niche markets in which price and efficiency are relatively unimportant. Sales in this market will drive the technology forward towards the point at which fuel cells will become economic for the introduction into the energy sector.
- Hydrogen electrolysers/fuel cells connected directly to wind turbines are a convenient way to balance out local fluctuations in the availability of wind power.
- The development of fuel cells and a hydrogen economy will provide new market opportunities and new jobs.
- Present knowledge indicates that hydrogen as an energy carrier will involve little environmental risk.

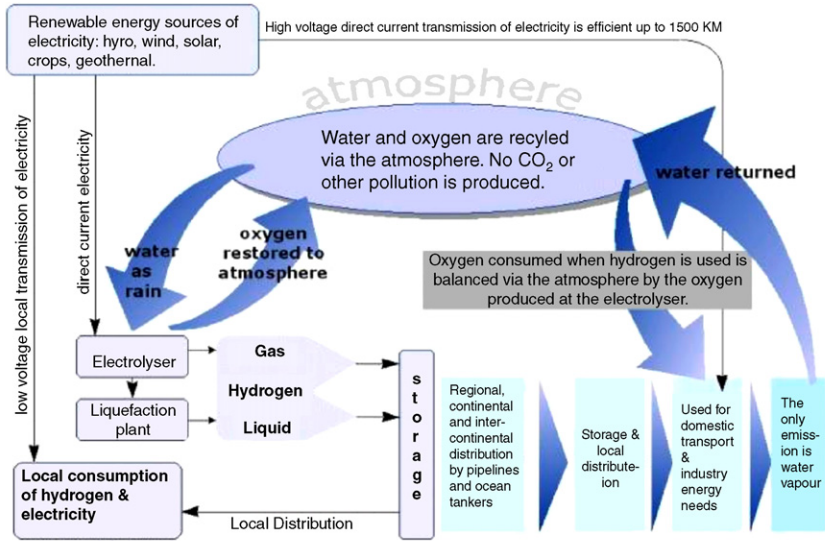


Fig. 1. Hydrogen-based energy system (*Source*: http://www.hydrogen.co.uk).

1.5. Barriers and challenges to hydrogen economy

A hydrogen-based society will require fundamental breakthroughs in both basic science and technology. There is a huge performance gap between what today's technologies can deliver and what a market-driven hydrogen economy will need. Most studies agree that key hydrogen technologies are still too inefficient and too expensive to meet our energy demands in the near future [7]. Most importantly:

- More efficient and cheaper ways to make hydrogen must be developed.
- Better storage systems for hydrogen in the transport sector are critically important.
- Fuel cell prices must fall, and their operating lifetime must be increased.
- A prerequisite for the introduction of fuel cell vehicles is an adequate hydrogen distribution infrastructure.

Major challenges in transition to hydrogen economy are described below in detail [8].

1.5.1. Competitiveness of technologies (R&D)

Lowering hydrogen fuel price requires improvements throughout the entire hydrogen economy, from production, processing, transportation, and storage, to distribution. The improvement in fuel cell vehicle technologies requires revolutionary breakthroughs in fuel cell technologies, and evolving improvements in drive train. The development of vehicle technologies and hydrogen production technologies must proceed in tandem to break the chicken and egg problem.

1.5.2. Market development

Transitioning to a hydrogen economy requires designing and implementing an economic incentive scheme to encourage the building of hydrogen infrastructures and market development of fuel cell vehicles. Initially, niche markets must be identified where hydrogen technologies can penetrate the market with limited economic incentives. As technology learning and economy of scale drive down technology and fuel costs, hydrogen technologies will expand.

1.5.3. Build-up infrastructure

Transporting hydrogen is a very significant part of the cost of the delivered product. The design of infrastructure, including gas pipelines and rail lines for delivering inputs for producing hydrogen will be an integral part of the delivery system. The challenges in achieving the best delivery system include selection of the site for hydrogen production and establishing a viable transportation network.

1.5.4. Competing markets—hybrid vehicles

Government policies must play a role in transforming the energy system to a hydrogen economy. Hybrid vehicles, which share many common technologies, are becoming more energy efficient and cost-effective, as are the fuel cell vehicles. However, as hydrogen technologies penetrate the market, gasoline prices will decline and hybrid vehicles could be more competitive than the fuel cell vehicles, dampening the penetration of hydrogen technologies.

1.5.5. Managing technological "lock-in"

A unique feature of the hydrogen energy system is that in each aspect of the system there are several competing technologies, with the more sustainable option appearing further away commercially. The challenge is to navigate a route that generates sufficient adoption of hydrogen technologies to enable the hydrogen economy, without allowing the less sustainable technologies to become so dominant that others are suppressed. Examples include, production of hydrogen from non-renewable natural gas rather than renewables; large-scale production and processing necessitating long distance transport rather than local production; combustion of hydrogen in nitrogen oxide-producing internal combustion engines rather than fuel cells.

2. The current energy situation in Pakistan

Pakistan's future energy system looks rather uncertain. In recent years, the combination of rising oil consumption and flat oil production in Pakistan has led to rising oil imports from Middle East exporters. Natural gas accounts for the largest share of Pakistan's energy use, amounting to nearly 50 percent of total energy consumption. Pakistan currently consumes all of its domestic natural gas production, but without higher production

Pakistan will need to become a natural gas importer. As a result, Pakistan is exploring several pipeline and LNG import options to meet the expected growth in natural gas demand. Coal currently plays only a minor role in Pakistan's energy mix, although the country contains an estimated 3303 million tonnes of proven recoverable reserves. Pakistan's electricity demand is rising rapidly. According to government estimates, generating capacity needs to grow by 50% by 2010 in order to meet expected demand [9,10].

Pakistan has an aggressive strategy to increase the share of renewable energy to 10% by 2015. Pakistan's geography and climate give it great hydropower, solar and wind energy potential [11].

3. Envisaged road map to hydrogen economy in Pakistan

Pakistan is lacking a vision and strategy for hydrogen in order to be prepared for business opportunities and potential niche markets of the hydrogen economy. There have been a few studies on the subject [12,13] but a detailed analysis of drivers and barriers, key challenges and actors, and the necessary measures is needed to bridge the gap between the present and the future vision, and to lay the foundation for a hydrogen economy roadmap for Pakistan.

The transition to a hydrogen-based energy economy should be gradual and in phases. By the middle of this century, Pakistan can be on its way for clean, renewable, and secure energy system.

3.1. Near-term

The application of hydrogen can start with niche applications distributed around the country. This includes, for example, city buses in areas facing air quality problems [14]. At first, hydrogen can be used for transportation by mixing it with natural gas in internal combustion engines; this would increase engine performance and decrease pollution. Fully hydrogen-powered fuel cell vehicles can be introduced gradually. These are zero-emission vehicles emitting only water vapor in exhaust.

Due to lack of infrastructure for transport and distribution of hydrogen on the one hand, and the presence of a well-developed natural gas pipeline infrastructure on the other hand, initially hydrogen can be produced on-site locally through steam reforming of natural gas [14].

After this initial stage, the local hydrogen communities and refuelling stations can be connected to a larger hydrogen transport and distribution pipeline infrastructure, and local production can be supplemented and finally replaced by large-scale production facilities which offer the possibility for applying carbon capture and sequestration [14].

3.2. Mid-term

Restructuring of the electric utility industry can present opportunities for distributed generation, where hydrogen-powered fuel cells provide on-site generation of electricity. In addition, these fuel cells can also produce thermal energy for hot water and industrial processes. Large-scale production of hydrogen can be increasingly through gasification of coal. Biomass in the form of agricultural residues and municipal solid wastes can also be utilized to produce hydrogen through gasification or pyrolysis. Carbon capture and sequestration technologies can accompany the large-scale production.

In the mid-term, an increasing number of hydrogen-fueled zero-emission vehicles are expected on the roads, due to improvements in on-board storage technologies. This, in turn, can provide stimulus for building a hydrogen infrastructure along dedicated transportation corridors or clusters of use.

3.3. Long-term

Strong hydrogen markets and a growing hydrogen infrastructure can open opportunities for renewable hydrogen systems. The intermittency of renewable electricity can create a market for hydrogen produced by electrolysis, to be used for peak levelling, making full use of the available renewable energy resources which may be at their most productive at times of low electricity demand. The current experience with wind technologies show that hydrogen may provide a much needed solution for managing intermittent nature of wind energy [8]. The fuel cells can use hydrogen to provide electricity during higher demand periods or to supplement the intermittent energy sources.

This era can witness the emergence and growth of advanced technologies that produce hydrogen from water and sunlight, and that store hydrogen in high-energy-density systems. Market penetration of advanced technologies to produce, store, and use hydrogen can signal the institution of the hydrogen economy.

4. Conclusions and recommendations

A combination of fuel cells and a hydrogen infrastructure is a way forward to combat the long-term challenges of climate change and energy security for Pakistan. Present knowledge indicates that large-scale use of hydrogen will pose no major environmental risk. Hydrogen is also no more hazardous than conventional fuels, as long as the proper technical standards and safety rules are used. The hydrogen economy potentially offers the possibility to deliver a range of benefits for the country including reducing dependence on oil imports, environmental sustainability and economic competitiveness. However, significant challenges exist and these are unlikely to be overcome without serious efforts. The following recommendations are made to put Pakistan on the way to a hydrogen economy:

- Clear and continuous political support for the development of the hydrogen economy needs to be provided.
- Partnerships should be developed with countries which are making headway in hydrogen technologies.
- Increased level of investment into R&D of hydrogen and fuel cells is required to overcome the technological barriers.

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